(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 683 242 B1

(12) EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:
06.05.1999 Bulletin 1999/18

(51) Int Cl.[6]: **C22F 1/16**, C22C 14/00, C22F 1/18

(21) Application number: **95301232.5**

(22) Date of filing: **27.02.1995**

(54) Method for making titanium alloy products

Verfahren zur Herstellung von Produkten aus Titanlegierung

Méthode de fabrication de produits en alliage de titane

(84) Designated Contracting States:
DE FR GB

(30) Priority: **23.03.1994 JP 51640/94**

(43) Date of publication of application:
22.11.1995 Bulletin 1995/47

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- **PATENT ABSTRACTS OF JAPAN vol. 017 no. 373 (C-1083) ,14 July 1993 & JP-A-05 059510 (NKK CORP) 9 March 1993,**
- **PATENT ABSTRACTS OF JAPAN vol. 013 no. 011 (C-558) ,11 January 1989 & JP-A-63 219558 (NIPPON MINING CO LTD) 13 September 1988,**
- **PATENT ABSTRACTS OF JAPAN vol. 014 no. 037 (C-680) ,24 January 1990 & JP-A-01 272750 (NIPPON STEEL CORP) 31 October 1989,**
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Description

1. Field of the Invention

[0001] The present invention relates to a method for making titanium alloy products having high strength and ductility.

2. Description of the related Arts

[0002] Titanium alloys have been widely used in aerospace applications for their advantages of high ductility and strength. In recent years, they have also been introduced in consumer product applications. High-strength type titanium alloys, typical of which is Ti-6Al-4V, however, have a disadvantage of high working cost due to their poor workability in general.

[0003] To overcome such a disadvantage, a superplastic forming / diffusion bonding method has been developed and used as a new forming method (" A Study on Fabrication Method of Integrated Light Titanium Sheet Metal Structure by Superplastic Forming / Diffusion Bonding", Makoto Ohsumi et al., Mitsubishi Heavy Industries Technical Review Vol. 20, No. 4, (1983-7), hereinafter called Prior Art 1). This forming method is to heat a titanium alloy to a predetermined temperature in $\alpha + \beta$-phase, and to form it at a low strain rate, by which a component of a final product shape or its similar shape can be formed.

[0004] However, the above-described forming method has problems as described below. For the most widely used Ti-6Al-4V alloy, the structure becomes coarse due to grain growth during superplastic forming because the superplastic forming temperature is as high as a temparature from 900 to 950°C, so that deterioration in mechanical properties (for example, decrease in strength and ductility) occurs.

[0005] For the Ti-6Al-4V alloy, the strength can be increased by rendering heat treatment of solution treatment and aging, but rapid cooling such as water quenching is needed in cooling after solution treatment. Therefore, it is almost impossible to apply this alloy to superplastically formed components. The superplastic forming is mainly applied to thin sheets. If a sheet component undergoes water quenching, quenching strains due to thermal stresses are developed, so that the component cannot function as a product.

[0006] Further, for the Ti-6Al-4V alloy, the reduction in forming cost is limited because of its high forming temperature. Therefore, the development of a titanium alloy which allows superplastic forming at lower temperatures has been attempted ("Enhanced Superplasticity and Strength in Modified Ti-6Al-4V Alloys ", J. A. Wert and N. E. Paton, Metallurgical Transactions A, Volume 14A, December 1983, p.2535-2544, hereinafter called Prior Art 2).

[0007] In accordance with the requirements shown in Prior Art 2, some of the inventors of the present invention have developed a titanium alloy for superplastic forming which has a superplastic forming temperature 100 °C or more lower than that of the above-described Ti-6Al-4V alloy (Japanese Unexamined Patent Publication Laid-Open No. 3-274238, hereinafter called Prior Art 3). Specifically, the use of an alloy, whose typical composition is Ti-4.5Al-3V-2Mo-2Fe, remarkedly decreases the superplastic forming temperature.

[0008] In the above-mentioned Prior Arts 1 to 3, however, the following four problems remain to be solved.

[0009] Firstly, quenching strains are developed in solution treatment after superplastic forming, and high strength and ductility cannot necessarily be obtained by solution treatment and subsequent heat treatment.

[0010] Secondly, in terms of cost, it is undesirable to repeat the solution treatment on a superplastic component. Therefore, the establishment of an alternative, efficient manufacturing technique is expected.

[0011] Thirdly, deterioration in material properties takes place due to superplastic forming, so that their strength and ductility are prone to decrease.

[0012] Fourthly, the establishment of a superplastic forming /diffusion bonding process is expected so that it can achieve excellent diffusion bonding strength.

[0013] Japanese patent application No. JP-A-5059510 discloses a method for manufacturing an $\alpha + \beta$ type titanium alloy having excellent strength, ductility and toughness after aging. Titanium alloys of a specified composition are solution treated by heating to a temperature in the range from (β-transus - 150°C) to less than the β-transus, then cooled at a cooling rate of 0.5 to 10°C/sec. The cooled material is then subjected to aging treatment in the temperature range 400 to 600°C.

[0014] Japanese patent application No. JP-A-63219558 discloses a heat treatment for Ti-6Al-4V alloy material, aimed at depositing the alpha phase from the residual beta phase, thereby improving the strength of the material. Specifically, the material is hot worked in the ($\alpha + \beta$) region and then held for a period in the temperature range 800 to 1050°C. The material is slowly cooled to 600 to 800°C, held at this temperature for a spell and then cooled in air at a rate of at least 0.15°C/sec to about 300°C. Finally, the material is aged at 450-650°C.

SUMMARY OF THE INVENTION

[0015] It is the first object if the invention to provide a method for making α + β-titanium alloy products having high strength and ductility, which has a composition without generation of quenching strains after superplastic forming and without the need for solution treatment, by properly establishing the cooling conditions after superplastics forming and the subsequent heat treatment conditions.

[0016] It is the second object of the invention to provide a method for making α + β-titanium alloy products, which can efficiently obtain the superplastically formed products having high strength and high ductility.

[0017] It is the third object of the invention to provide a method for making α + β-titanium alloy products which produces less deterioration in material properties due to superplastic forming and has much higher strength and ductility.

[0018] It is the fourth object of the invention to provide a method for making α + β-titanium alloy products, which includes a diffusion bonding process capable of achieving excellent diffusion bonding strength.

[0019] From the viewpoint described below, the target value of the strength after superplastic forming was set at 105 kgf/mm^2, 5 percent higher than the strength of Ti-6Al-4V alloy, preferably 110 kgf/mm^2, 10 percent higher. The above-mentioned Prior Art 1 describes a fact that for the Ti-6Al-4V alloy, the strength decreases by 5 to 10 percent in superplastic forming, and the tensile strength after superplastic forming is about 100 kgf/mm^2. Normally, in order for a new material or new process to be used, it is said that the enhancement in properties by 5 percent to 10 percent or more is needed. Therefore, in this application, tentative target properties were set at 5 to 10 percent improvement on the strength of the Ti-6Al-4V alloy.

[0020] To attain the above-mentioned objects, the present invention provides a method for making titanium alloy products comprising the steps of:

(a) superplastically forming at least two components of α + β-titanium alloy at a temperature of at most β-transus, said α + β-titanium alloy comprising the following constituents in proportions by weight: 3.45 to 5% Al; 2.1 to 5% V; 0.85 to 2.85% Mo; 0.85 to 3.15% Fe; 0.01 to 0.25% 0 and the balance titanium, apart from incidental elements and impurities, if any;
(b) heating each superplastically formed titanium alloy component to a temperature ranging from the superplastic-forming temperature plus 5°C to less than β-transus;
(c) diffusion bonding the heated titanium alloy components to each other;
(d) cooling the diffusion-bonded titanium alloy components at a cooling rate of 0.05 to 5°C/sec; and
(e) aging the cooled titanium alloy components at a temperature of 400 to 600°C.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021]

FIG. 1 shows the effect of cooling rate after superplastic forming on tensile properties after aging treatment;
FIG. 2 shows the effect of aging treatment temperature on tensile strength of superplastically formed product;
FIG. 3 shows a method of measuring thermal strain of superplastically formed product after cooling;
FIG. 4 shows the effect of heating temperature after superplastic forming on tensile properties after aging treatment;
FIG. 5 shows the effect of diffusion bonding temperature after superplastic forming on diffusion bonding strength after aging treatment; and
FIG. 6 shows the effect of diffusion bonding temperature after superplastic forming on tensile properties after aging treatment.

DESCRIPTION OF THE PREFERRED EMBODIMENT

[0022] The inventors obtained the following knowledge as a result of repeated studies made earnestly to find an alloy having such properties and its manufacturing conditions.

[0023] We found that some of the α + β-titanium alloys having the chemical composition disclosed in the above-mentioned Prior Art 3 are alloys having a component suitable for solving the above problems. We also found that a technique for manufacturing a superplastically formed component having much higher strength and ductility than before can be established by performing heat treatment by a method described below after these alloys are superplastically formed, and a formed component having excellent strength in diffusion bonding can be manufactured. As a result of further detailed studies made focusing on this point, we found that there exists a composition which is not included in Prior Art 3 but can achieve the same effect.

[0024] Specifically, it was found that the above first and second problems can be solved by specifying a chemical composition from the above viewpoint, by performing cooling after solution treatment at a proper cooling rate which

can offer high strength and ductility after aging treatment without giving thermal strains to the formed component after superplastic forming, and subsequently by performing aging treatment in a proper temperature range.

[0025] Also, it was found that the third problem can be solved by heating the formed component to a predetermined temperature without being cooled to room temperature after forming is performed at an optimum superplastic forming temperature at which the structure does not become coarse during the superplastic forming and by subsequently performing the above-mentioned heat treatment, and even higher strength can be attained.

[0026] Furthermore, it was found that for the fourth problem, both of the bonding strength and the strength of the formed component can be improved at the same time by increasing the temperature of the formed component to perform diffusion bonding after superplastic forming, and a superplastic forming/diffusion bonding process can be established.

[0027] Next, the present invention will be described in detail.

[0028] First, the reasons why the chemical composition is limited as described above in the present invention will be described.

[0029] Aℓ (aluminum): Aℓ is one of α stabilizing elements, and the element indispensable to the $\alpha + \beta$-titanium alloy. If Aℓ content is less than 3.45 wt%, sufficient strength cannot be obtained. If Aℓ content exceeds 5 wt%, the workability, especially at low temperatures, significantly deteriorates, and the fatigue life strength worsens. Therefore, Aℓ content was specified at the range from 3.45 to 5 wt%.

[0030] 0 (oxygen): Oxygen content equal to that of the ordinary $\alpha + \beta$ -titanium alloy is desirable. If oxygen content is less than 0.01 wt%, the contribution to the increase in strength is insufficient, and if oxygen content exceeds 0.25 wt%, the ductility decreases. Therefore, oxygen content was specified at the range from 0.01 to 0.25 wt%.

[0031] V (vanadium): V has little effect of stabilizing β-phase, but it is an important element to reduce the β-transus. However, if V content is less than 2.1 wt%, the reduction in β-transus is insufficient, and the effect of stabilizing β-phase cannot be achieved. If V content exceeds 5.0 wt%, the stability of β-phase becomes too high, so that the increase in strength due to aging treatment cannot be obtained sufficiently, and the cost becomes high because V is an expensive element. Therefore, V content was specified at the range from 2.1 to 5.0 wt%.

[0032] Mo (molybdenum): Mo has effects of stabilizing β-phase and retarding grain growth. However, if Mo content is less than 0.85 wt%, crystal grains become coarse in annealing, so that the desired effect cannot be achieved. If Mo content exceeds 2.85 wt%, the stability of β-phase becomes too high, so that the increase in strength due to aging treatment cannot be obtained. Therefore, Mo content was specified at 0.85 to 2.85 wt%.

[0033] Fe (iron): Fe stabilizes β-phase, especially strengthening β-phase, and greatly contributes to the increase in strength after solution and aging treatment. Also, because Fe has a high diffusivity in titanium, it has an effect of reducing the deformation resistance in superplastic forming, and improves diffusion bonding properties. If Fe content is less than 0.85 wt%, the effect of strengthening is insufficient, and both of the effect of reducing the deformation resistance in superplastic forming and the effect of improving the diffusion bonding properties are insufficient. If Fe content exceeds 3.15 wt%, the stability of β-phase becomes too high, so that the superplastic properties deteriorate, and the increase in strength in aging treatment cannot be obtained. Therefore, Fe content was specified at 0.85 to 3.15 wt%.

[0034] Impurity elements normally contained in the $\alpha + \beta$-titanium alloy and other additional elements which have no influence on the effects of the present invention are allowed.

[0035] Next, the reasons why the cooling conditions and heat treatment conditions after superplastic forming are limited are described below.

[0036] The cooling rate after superplastic forming must be one which is not too high in order to prevent thermal strains and must be one which is not too low in order to obtain a sufficient increase in strength after aging treatment. If the cooling rate is too high, the strength after aging treatment becomes too high, the ductility being lost, so that the formed component cannot be used as a practical component. Therefore, the cooling rate after superplastic forming was specified at 0.05 to 5 °C/sec in consideration of above factors.

[0037] FIG. 1 shows tensile properties of superplastically formed components at room temperature. The superplastically formed components were manufactured as follows: After a Ti-4.38% Aℓ -3.02%V-2.03%Mo-1.91%Fe-0.085%O alloy was superplastically formed at 795°C, the formed component was cooled to room temperature at different cooling rates, and subsequently aging treatment was performed at 510 °C for 6 hours. As seen from FIG. 1, if the cooling rate is lower than 0.05 °C /sec, the increase in strength after aging treatment cannot be obtained. If the cooling rate exceeds 5 °C /sec, a decrease in ductility is found though the strength is high, the elongation being less than 5%, which presents a problem in practical use. Also, at cooling rates exceeding 5 °C/sec, large thermal strains were produced on the formed body after superplastic forming.

[0038] In case that the cooling rate is 0.05 to 1 °C /sec, more preferable elongation is obtained. In case that the cooling rate is 1 to 5 °C /sec, more preferable strength is obtained. The cooling rate of 0.3 to 1°C /sec is more desirable in elongation and strength.

[0039] If the aging treatment temperature is lower than 400 °C, the temperature is too low to improve the strength

after aging treatment. If the aging treatment temperature exceeds 600 °C, the strength enhancement is undesirably lost due to " over-aging". Therefore, the aging treatment temperature was specified at the range from 400 to 600 °C.

[0040] In case that aging treatment temperature is 400 to 500 °C, more preferable tensile strength is obtained. In case that aging treatment temperature is 500 to 600°C, more preferable elongation is obtained. In case that aging treatment temperature is 450 to 550 °C, more preferable 0.2% proof stress and tensile strength are obtained.

[0041] A α + β-titanium alloy having high strength and ductility can be obtained under the above conditions. In this case, the deterioration in material properties due to superplastic forming is inhibited, so that much higher strength can be obtained, by increasing the temperature of the formed body in a predetermined range after superplastic forming, and then by performing cooling and aging treatment under the above conditions. At this time, if the increased temperature range is less than 5 °C, the effect is not found, and if the increased temperature is not lower than the β-transus of that material, the microstructure becomes coarse, so that the mechanical properties after aging treatment, especially the ductility, deteriorate. Therefore, the temperature increased at this time was specified at a temperature which is 5°C or more higher than the superplastic forming temperature and lower than the β-transus. To further increase the strength, it is preferable that the increased temperature be 25°C or more higher than the superplastic forming temperature. In this case, it is desirable that the heating treatment is performed in a superplastic forming apparatus without cooling the formed component to room temperature.

[0042] Sufficient bonding strength can be obtained even if diffusion bonding is performed at the superplastic forming temperature after superplastic forming. Also, far higher bonding strength can be obtained by increasing the temperature of the superplastically formed component in a predetermined range to perform diffusion bonding after superplastic forming, and then by performing cooling and aging treatment under the above conditions. At this time, if the increased temperature range is less than 5 °C, the effect is not found, and if the increased temperature is not lower than the β-transus of that material, the microstructure becomes coarse, so that the mechanical properties after aging treatment, especially the ductility, deteriorate. Therefore, the temperature increased at this time was specified at a temperature which is 5 °C or more higher than the superplastic forming temperature and lower than the β-transus. To further increase the strength, it is preferable that the increased temperature be 25°C or more higher than the superplastic forming temperature. In this case too, it is desirable that the heating treatment is performed in a superplastic forming apparatus without cooling the formed component to room temperature.

[0043] The superplastic forming is carried out at a temperature of at most β-transus. The temperature of 750 to 825 °C is more preferable.

EXAMPLE

[0044] Next, comparative examples and examples of the present invention will be described in detail.

Example-1 (comparative)

[0045] After an ingot of α +β-titanium alloy which contains 4.38 wt% Aℓ, 3.02 wt% V, 2.03 wt% Mo, 1.91 wt% Fe, 0.085 wt% 0, 0.01 wt% C, 0.006 wt% N, and 0.0085 wt% H, and has a β-transus of 895 °C was heated to β-phase region and forged, the forged material was heated to α + β-phase region, and formed into a 2 mm-thick sheet by hot rolling. After being superplastically formed at 795 °C, this sheet material was cooled to room temperature at a cooling rate of 0.005 to 30 °C/sec, and then underwent aging treatment at 510 °C for 6 hours. The relationship between the cooling rate and the tensile properties at room temperature for this example is shown in Table 1 and FIG. 1.

TABLE 1

Cooling rate (°C/sec)	Tensile strength after cooling (kgf/mm^2)	Tensile strength after aging (kgf/mm^2)	Elongation after aging (%)	Thermal strain after cooling (%)
0.005	101.5	102.8	16.4	<1
0.03	100.8	101.2	16.0	<1
0.1	99.8	105.2	13.6	<1
0.3	100.4	111.5	11.8	<1
1	101.8	120.5	8.4	<1
3	99.5	129.4	7.3	<1
10	98.3	130.5	4.9	1.6

TABLE 1 (continued)

Cooling rate (°C/sec)	Tensile strength after cooling (kgf/mm^2)	Tensile strength after aging (kgf/mm^2)	Elongation after aging (%)	Thermal strain after cooling (%)
30	98.0	130.2	4.6	3.2

[0046] From Table 1 and FIG. 1, it is seen that if the cooling rate after superplastic forming is lower than 0.05 °C/sec, the increase in strength cannot be obtained, and if the cooling rate exceeds 5°C/sec, the elongation is less than 5% though high strength can be obtained, which presents a problem in practical use. It is found that if the cooling rate is in the range of 0.05 to 5 °C/sec, both of the strength and the elongation take satisfactory values.

[0047] Table 1 also shows the relationship between the thermal strain and the cooling rate for the formed component after superplastic forming and cooling. If the cooling rate exceeds 5°C/sec, the occurrence of remarkable thermal strain is found. The thermal strain was evaluated by using a value obtained by dividing the maximum value of the floating height from a surface plate by the length of side of the formed component. The floating height was measured with the superplastically formed component being placed on a surface plate as shown in FIG. 3.

[0048] Next, after being superplastically formed at 795 °C in the same manner as described above, a titanium alloy sheet having the above chemical composition was cooled to room temperature at a cooling rate of 1 °C /sec, and then underwent aging treatment in the temperature range of 300 to 700 °C for 1 hour to evaluate the tensile properties at room temperature. The results are shown in Table 2 and FIG. 2. As seen from Table 2 and FIG. 2, if the aging treatment temperature is lower than 400°C, aging hardening is insufficient, and if the temperature exceeds 600 °C, softening due to overaging occurs, so that the target strength not lower than 110 kgf/mm^2 cannot be obtained.

TABLE 2

Aging treatment temperature	0.2% proof stress (kgf/mm^2)	Tensile strength (kgf/mm^2)	Elongation (%)
300°C	99.7	104.3	18.5
400°C	100.1	110.6	16.4
480°C	108.3	127.5	10.1
510°C	106.0	122.4	12.2
560°C	105.2	114.1	13.5
600°C	102.4	109.9	15.8
700°C	95.4	100.6	17.9

<u>Example 2</u> (comparative)

[0049] After an ingot of α +β-titanium alloy which contains 4.52 wt% $A\ell$, 3.21 wt% V, 1.89 wt% Mo, 2.07 wt% Fe, 0.114 wt% O, 0.01 wt% C, 0.008 wt% N, and 0.0045 wt% H, and has a β-transus of 905 °C was heated to β-phase region and forged, the forged material was heated to α +β-Phase region, and formed into a 3 mm-thick sheet by hot rolling. After this sheet material is superplastically formed at 775 °C, the formed body was heated to temperatures from 778 °C (superplastic forming temperature + 3 °C) to 915 °C (β-transus + 10 °C), cooled to room temperature at a cooling rate of 0.5 °C/sec, and successively underwent aging treatment at 480 °C for 3 hours. The relationship between the heating temperature after superplastic forming and the tensile properties after aging treatment for this example is shown in Table 3 and FIG. 4. The tensile properties of a material which was cooled to room temperature at a cooling rate of 0.5 °C/sec without being heated after superplastic forming and underwent aging treatment at 480 °C for 3 hours are shown in Table 3 for comparison.

[0050] From Table 3 and FIG. 4, it is seen that the increase in strength can be obtained by heating the formed body by 5 °C or more at a temperature which is lower than the β-transus. Particularly for the formed component heated to a temperature not lower than the superplastic forming temperature plus 25°C, much higher strength can be obtained.

TABLE 3

Heating Temperature	0.2% proof stress (kgf/mm^2)	Tensile Strength (kgf/mm^2)	Elongation (%)
775°C	109.2	128.0	9.6

TABLE 3 (continued)

Heating Temperature	0.2% proof stress (kgf/mm^2)	Tensile Strength (kgf/mm^2)	Elongation (%)
778°C	109.3	128.1	9.5
785°C	110.8	129.9	9.0
810°C	112.6	131.8	7.6
840°C	114.5	132.7	7.0
870°C	114.8	133.0	6.6
915°C	114.6	132.9	3.5

Example 3 (comparative)

[0051] The titanium alloy sheet (3 mm thickness) shown in Example 2 is superplastically formed at 810 °C, successively subjected to diffusion bonding at that temperature, then cooled to room temperature at 1 °C/sec, and underwent aging treatment at 510 °C for 6 hours. The tensile properties of the superplastically formed portion at this time is shown in Table 4.

[0052] From this result, it is found that the same effects as those of Example 2 can be obtained even when diffusion bonding is performed after superplastic forming.

TABLE 4

	0.2% proof stress (kgf/mm^2)	Tensile strength (kgf/mm^2)	Elongation (kgf/mm^2)
As cooled	94.0	100.7	12.8
After aging treatment	110.4	120.0	8.3

Example 4 (according to the invention)

[0053] The titanium alloy sheet (2 mm thickness) shown in Example 1 is superplastically formed at 795 °C, successively heated to 820 °C, subjected to diffusion bonding at that temperature, then cooled to room temperature at 1 °C/sec, and underwent aging treatment at 510 °C for 6 hours. The tensile properties of the superplastically formed portion for this example is shown in Table 5.

[0054] As seen from Table 5, the same effects as those of Example 2 can be obtained even when heating and diffusion bonding are performed after superplastic forming.

TABLE 5

	0.2% proof stress (kgf/mm^2)	Tensile strength (kgf/mm^2)	Elongation (kgf/mm^2)
As cooled	94.9	101.5	11.7
After aging treatment	112.5	122.3	7.9

Example 5 (according to the invention)

[0055] The titanium alloy sheet (2 mm thickness) shown in Example 1 is superplastically formed at 775 °C, successively heated to temperatures from 778 to 910 °C, subjected to diffusion bonding at those temperatures, then cooled to room temperature at 0.5 °C/sec, and underwent aging treatment at 510 °C for 6 hours. The relationship between the diffusion bonding temperature and the bonding strength of the diffusion bonded portion is shown in Table 6 and FIG. 5, and the relationship between the diffusion bonding temperature and the strength of the superplastically formed portion is shown in Table 7 and FIG. 6.

TABLE 6

Heating temperature	Shearing strength of diffusion bonded portion (kgf/mm^2)
775°C	53.2
778°C	53.3

TABLE 6 (continued)

Heating temperature	Shearing strength of diffusion bonded portion (kgf/mm^2)
785°C	57.0
810°C	61.6
840°C	63.1
870°C	63.5
915°C	58.9

Table 7

Heating Temperature	0.2% proof stress (kgf/mm^2)	Tensile strength (kgf/mm^2)	Elongation (%)
775°C	100.9	118.4	10.2
778°C	101.3	118.3	10.1
785°C	104.5	120.2	9.0
810°C	106.3	122.5	7.6
840°C	108.4	125.0	6.7
870°C	108.6	125.8	5.9
915°C	106.9	124.7	3.5

[0056] From the figures in the tables above, it is found that both of the bonding strength and the strength of the superplastic-formed portion are increased by performing heating and diffusion bonding after superplastic forming.

Claims

1. A method for making a titanium alloy product comprising the steps of:

   (a) superplastically forming at least two components of $\alpha + \beta$-titanium alloy at a temperature of at most β-transus, said $\alpha + \beta$-titanium alloy comprising the following constituents in proportions by weight: 3.45 to 5% Al; 2.1 to 5% V; 0.85 to 2.85% Mo; 0.85 to 3.15% Fe; 0.01 to 0.25% 0 and the balance titanium, apart from incidental elements and impurities, if any;
   (b) heating each superplastically formed titanium alloy component to a temperature ranging from the superplastic-forming temperature plus 5°C to less than β-transus;
   (c) diffusion bonding the heated titanium alloy components to each other;
   (d) cooling the diffusion-bonded titanium alloy components at a cooling rate of 0.05 to 5°C/sec, and
   (e) aging the cooled titanium alloy components at a temperature of 400 to 600°C.

2. A method as claimed in claim 1, wherein said cooling rate of the titanium alloy is 0.05 to 1 °C/sec.

3. A method as claimed in claim 2, wherein said cooling rate of the titanium alloy is 0.3 to 1 °C/sec.

4. A method as claimed in claim 1, wherein said cooling rate of the titanium alloy is 1 to 5 °C/sec.

5. A method as claimed in claim 1, wherein said aging temperature is 400 to 500 °C.

6. A method as claimed in claim 1, wherein said aging temperature is 500 to 600 °C.

7. A method as claimed in claim 1, wherein said aging temperature is 450 to 550 °C.

8. A method as claimed in claim 1, wherein the temperature of the superplastic forming step is 750 to 825 °C.

Patentansprüche

1. Verfahren zur Herstellung eines Titanlegierungsproduktes, umfassend die folgenden Schritte:

   (a) superplastisches Formen von wenigstens zwei Komponenten aus einer α + β-Titanlegierung bei einer Temperatur von maximal dem β-Transus, wobei die α + β-Titanlegierung die folgenden Bestandteile in Gew. % umfaßt: 3,45 bis 5% Al; 2,1 bis 5% V; 0,85 bis 2,85% Mo; 0,85 bis 3,15% Fe; 0,01 bis 0,25% O und Rest Titan, neben unvermeidbaren Elementen und Verunreinigungen, falls vorhanden;

   (b) Erwärmen einer jeden superplastisch geformten Titanlegierungskomponente auf eine Temperatur im Bereich von der superplastischen Formtemperatur +5°C bis weniger als dem β-Transus;

   (c) Diffusionsbindung der erwärmten Titanlegierungskomponenten aneinander;

   (d) Kühlen der diffusionsgebundenen Titanlegierungskomponenten bei einer Kühlrate von 0,05 bis 5°C/s, und

   (e) Altern der gekühlten Titanlegierungskomponenten bei einer Temperatur von 400 bis 600°C.

2. Verfahren nach Anspruch 1, worin die Kühlrate der Titanlegierung 0,05 bis 1°C/s ist.

3. Verfahren nach Anspruch 2, worin die Kühlrate der Titanlegierung 0,3 bis 1°C/s ist.

4. Verfahren nach Anspruch 1, worin die Kühlrate der Titanlegierung 1 bis 5°C/s ist.

5. Verfahren nach Anspruch 1, worin die Alterungstemperatur 400 bis 500°C ist.

6. Verfahren nach Anspruch 1, worin die Alterungstemperatur 500 bis 600°C ist.

7. Verfahren nach Anspruch 1, worin die Alterungstemperatur 450 bis 550°C ist.

8. Verfahren nach Anspruch 1, worin die Temperatur des superplastischen Formschrittes 750 bis 825°C ist.

Revendications

1. Procédé pour fabriquer un produit en alliage de titane, comprenant les étapes consistant à :

   (a) façonner de manière superplastique au moins deux composants d'alliage de titane (α + β) à une température au plus égale à la température de transition β, ledit alliage de titane (α + β) comprenant les constituants suivants en les proportions pondérales suivantes : 3,45 à 5 % de Al ; 2,1 à à 5 % de V ; 0,85 à 2,85 % de Mo ; 0,85 à 3,15 % de Fe ; 0,01 à 0,25 % de O, et le reste étant du titane, à part les éléments et impuretés fortuits, s'il y en a ;
   (b) chauffage de chaque composant en alliage de titane façonné de manière superplastique à une température située dans la plage allant de la température de façonnage superplastique plus 5°C à une température inférieure à la température de transition β;
   (c) liaison par diffusion des composants d'alliage de titane chauffés entre eux ;
   (d) refroidissement des composants d'alliage de titane liés par diffusion à une vitesse de refroidissement de 0,05 à 5°C/s, et
   (e) vieillissement des composants d'alliage de titane refroidis à une température de 400 à 600°C.

2. Procédé selon la revendication 1, dans lequel ladite vitesse de refroidissement de l'alliage de titane est de 0,05 à 1°C/s.

3. Procédé selon la revendication 2, dans lequel ladite vitesse de refroidissement de l'alliage de titane est de 0,3 à 1°C/s.

4. Procédé selon la revendication 1, dans lequel ladite vitesse de refroidissement de l'alliage de titane est de 1 à 5°C/s.

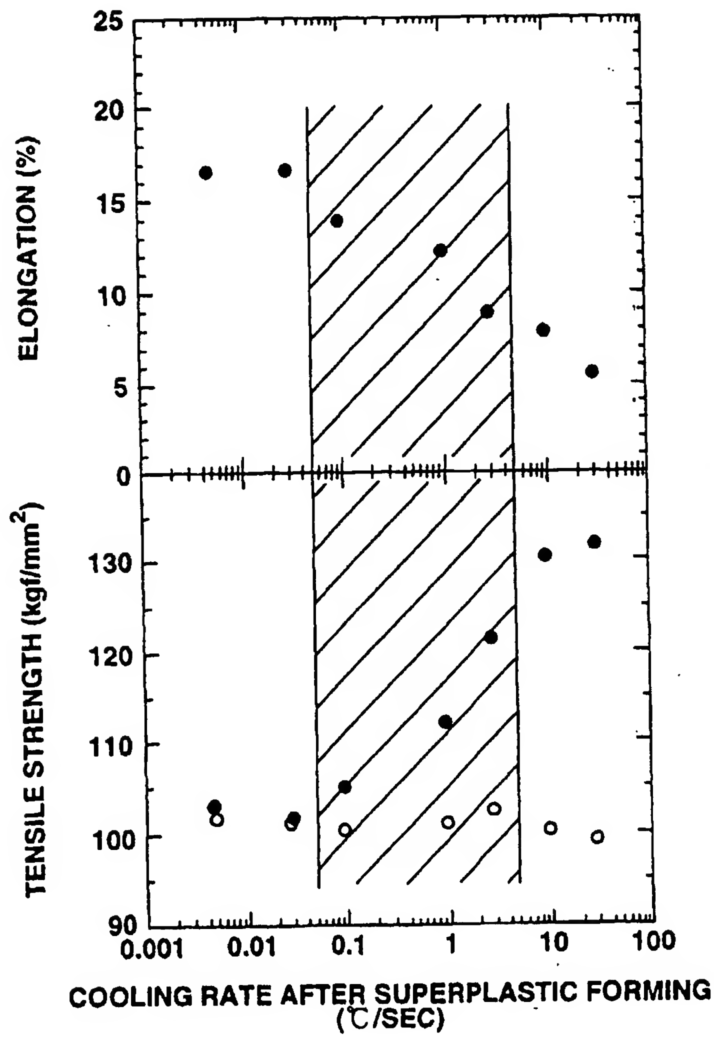
5. Procédé selon la revendication 1, dans lequel ladite température de vieillissement est de 400 à 500°C.

6. Procédé selon la revendication 1, dans lequel ladite température de vieillissement est de 500 à 600°C.

7. Procédé selon la revendication 1, dans lequel ladite température de vieillissement est de 450 à 550°C.

8. Procédé selon la revendication 1, dans lequel la température de l'étape de façonnage superplastique est de 750 à 825°C.

FIG.1



● TENSILE STRENGTH AFTER AGING TREATMENT

○ TENSILE STRENGTH OF AS COOLED MATERIAL AFTER SUPERPLASTIC FORMING

FIG.2

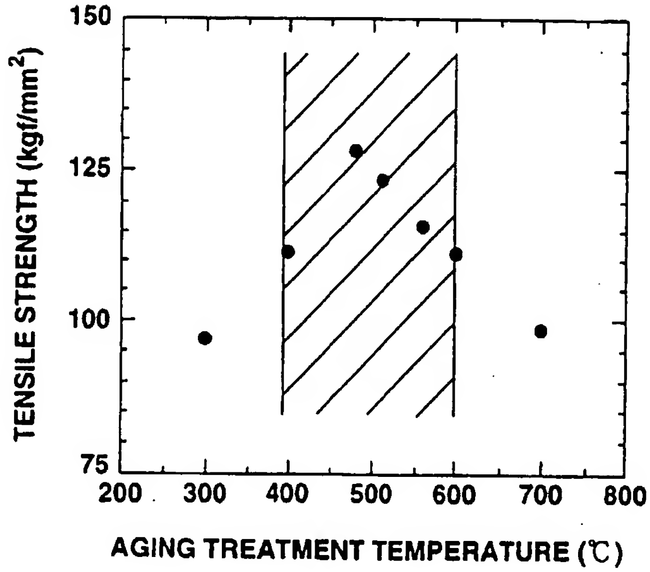
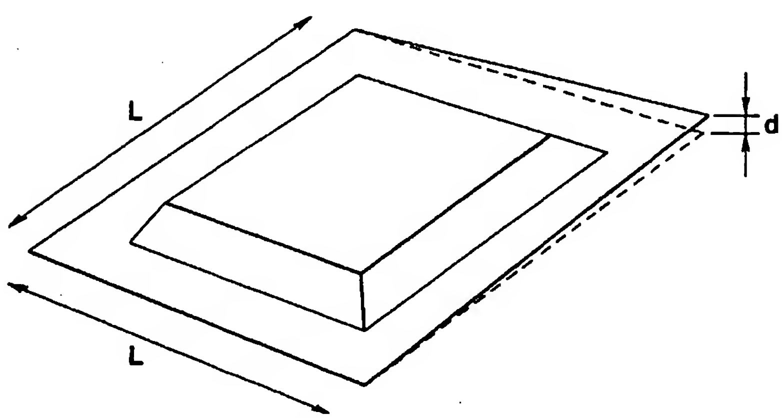


FIG.3



THERMAL STRAIN (%)=d/L×100

FIG.4

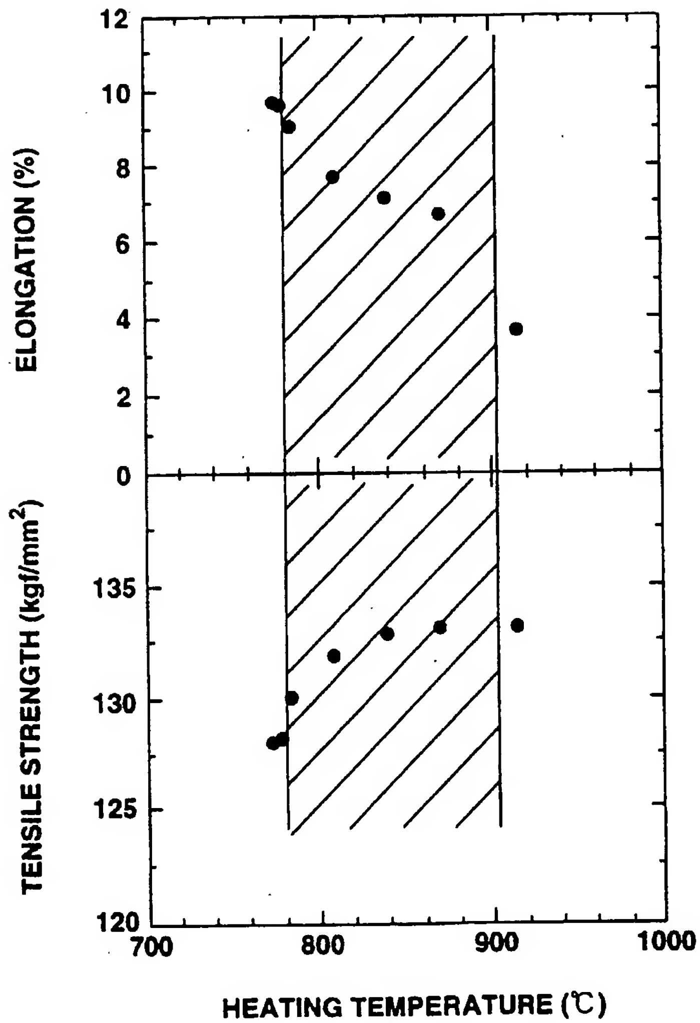

12
10
8
6
4
2
0
ELONGATION (%)
135
130
125
120
TENSILE STRENGTH (kgf/mm^2)
700
800
900
1000
HEATING TEMPERATURE (℃)

FIG.5

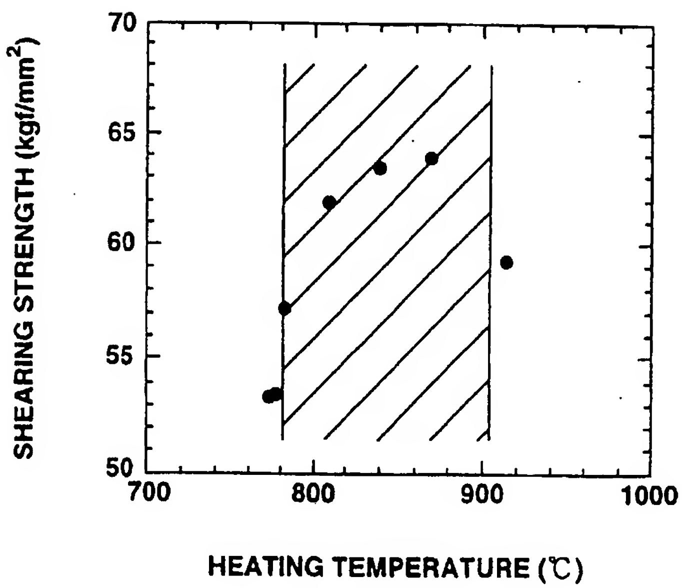
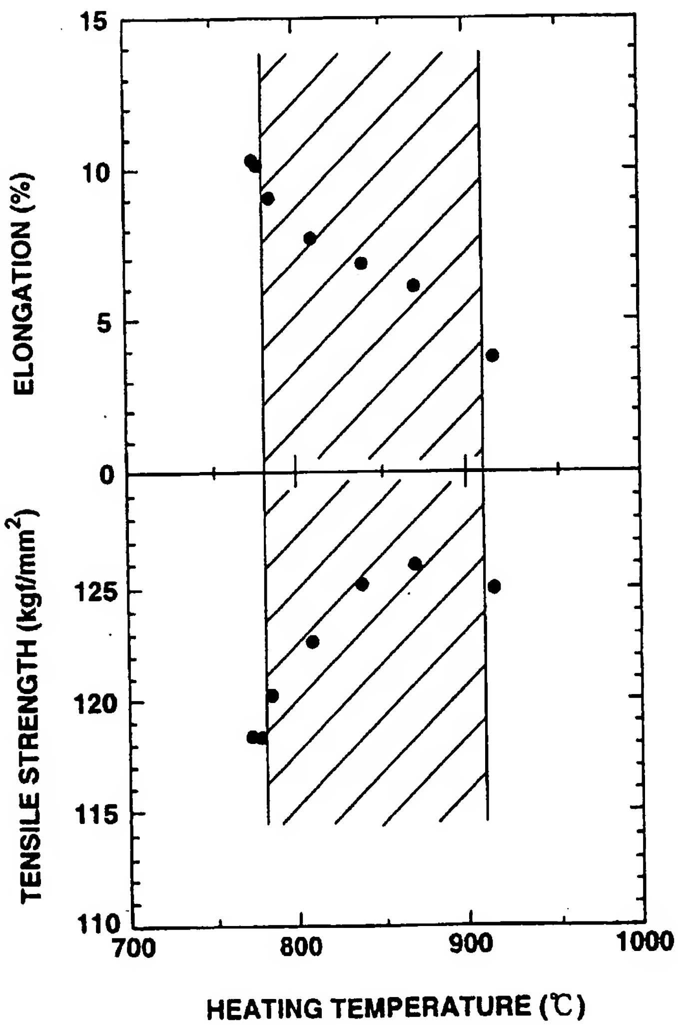

70
65
60
55
50
700
800
900
1000
SHEARING STRENGTH (kgf/mm²)
HEATING TEMPERATURE (℃)

FIG.6


ELONGATION (%)
15
10
5
0
TENSILE STRENGTH (kgf/mm^2)
125
120
115
110
700
800
900
1000
HEATING TEMPERATURE (℃)